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CO-EVOLUTION OF DESIGN TACTICS AND CSCWD SYSTEMS: METHODOLOGICAL CIRCULATION AND THE TATIN-PIC PLATFORM

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ABSTRACT
This paper proposes a design strategy and a Computer Supported Cooperative Work in Design (CSCWD) system, which have co-evolved together to meet the goal of improving the Preliminary Design Process (PDP). Because there is no consensus for a definition of PDP, here we define it as an evolutionary, iterative and heuristic process.
Methodological Circulation is a design strategy where multidisciplinary design teams explore the solution space of a problem, while a project manager facilitates this heuristic and effectual exploration by determining the way forward through appropriate decision-making.
Creating a computer support system for this design strategy requires considering 4 factors at the base of this co-evolutionary approach: the problem-solving cognitivist posture, the dynamic of the preliminary design activities, the nature of collaboration, and the composition of the design group and management. We present how these factors have mutually influenced our CSCWD system called TATIN-PIC and the MC. We present the preliminary results of ethnographic observations of design teams performing project planning within the TATIN-PIC environment and a traditional designer's environment.

Keywords: design methodology, early design phases, collaborative design, methodological circulation, computer supported cooperative work in design

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1 INTRODUCTION

The path that leads to new products, services, processes and business models is not known in advance. As Chesbrough (2003) says, "*Commercializing a new technology requires the resolution of both technical and market uncertainty, you cannot anticipate the best path forward from the very beginning. You simply don't know all the possibilities in advance.*" Though the future might be unpredictable, it is still controllable according to the effectuation concept (Sarasvathy, 2001).

We envision design as an iterative and heuristic process, evolving across different design activities. A design activity could be re-examined or even re-performed while considering new information. Generally, the design process starts from a problem (either well or ill-defined), passes through activities of conceptualization and planning, to reach a detailed design phase, in which activities concerning the architecture and components are performed (Scaravetti, 2004). A design team simply does not know the shortest path to the final result in advance. Design can be a collaborative multidisciplinary process conducted by a design team (Shiba, 1995) allowing it to be more effective and responsive to the challenges of the markets. Design teams include, but are not limited to, designers, managers, experts and users.

Designers follow a design strategy to choose the appropriate design methods, which can be defined as the set of procedures and techniques used during the design process. These design strategies and methods are often based on existing support tools. Computer support systems have been introduced to enhance the overall performance of the design team during the design process.

Despite the fact that the preliminary design process (PDP) is the most impactful in terms of performances and costs (McLeamy, 2004), such computer support systems address mainly the detailed design process (e.g. Computer Aided Design tools). Moreover, these systems are conceived for mono-user interactions, in contrast with the collaborative nature of design activities (Dietz, 2001) (Forlines, 2008).

Although the evolution of such systems toward Computer Supported Cooperative Work in Design (CSCWD) systems is essential, this is not the only aspect worthy of consideration. In our knowledge, there are no propositions of design methods adapted for CSCWD systems (Wang et al., 2000).

Our approach to address this twofold gap is co-evolutionary: CSCWD systems and design methods mutually influence each other and should co-evolve together (Guerra et al., 2012). We address four key factors for validating this co-evolutionary approach: the problem-solving cognitivist posture, the dynamics of the preliminary design activities, the nature of collaboration, and the composition of the design group and management.

Methodological Circulation (MC) is a design strategy implemented in the University of Technology of Compiegne (UTC)'s Innovation Centre[1], to address the preliminary design process.

Sub-section 2.1 describes the *enactive exploration of the problem/solutions space*, which is the core of the problem-solving posture of MC. Sub-section 2.2 presents our vision concerning the dynamic of the preliminary design process. In Sub-section 2.3 we discuss the notion of collaboration during design activities. Sub-section 2.4 details the role of internal low-level management (the project manager) and the role of external top-level management (the company management). With this consideration, the concept of the *design toolbox* is presented. In subsection 2.5, we summarize the hypotheses that lead toward the co-evolutionary approach we present.

In Section 3, we describe the TATIN-PIC platform, a CSCWD support system. Section 4 presents our ethnographic design observation based on the preliminary design planning activity performed by engineering practitioners. Subsection 4.1 presents the design observation protocol while subsection 4.2 details the methods of analysis and the results. Finally, section 5 is dedicated to the conclusion and perspectives for future work.

2 METHODOLOGICAL CIRCULATION: A NEW PRELIMINARY DESIGN TACTIC

2.1 Methodological Circulation: the enactive exploration of the solutions space

MC originates from the union between design thinking (Simon, 1969) (Rowe, 1987) (Brown, 2009) (Plattner et al., 2010) and effectual approaches (Sarasvathy, 2001). MC supports an enactive

[1] The Université de Technologie de Compiègne, is a public institution specialized in science, engineering and technology awarding degrees at the master and PhD level while undertaking interdisciplinary research.

organisation of knowledge (Bruner, 1990). Humans obtain knowledge through perception-action interaction in the environment (Lenay and Steiner, 2010) and use this knowledge during problem solving activities. The human cognitive problem-solving process (Newell and Simon, 1972) sees an exploration (Wood et al., 2000) of the problem/solutions space (Hatchuel and Weil, 2009) (creativity-divergence) until a solution is found (convergence) (Millier, 2002).
However, it is impossible to explore the entirety of the problem/solutions space due to the constraints imposed by the project ecosystem. Therefore, a designer's role is to find satisfying (Dorst, 1996) or adequate solutions (Cross and Clayburn Cross, 1995).
This enactive approach feeds directly into what we call the *echo feedback-based exploration* of the paths within the problem/solutions space. Designers do not know in advance which paths to follow to reach a satisfying solution; the design problem and solution paths are built enactively.
The CSCWD system should support this problem/solutions space exploration by amplifying the pool of available knowledge.

2.2 Dynamics of preliminary design process

The PDP is a sub-process of the design process that is composed of a set of design activities. There are no standards regarding the composition of this set of design activities but there exists at least a general description of the activities performed (Scaravetti, 2004).

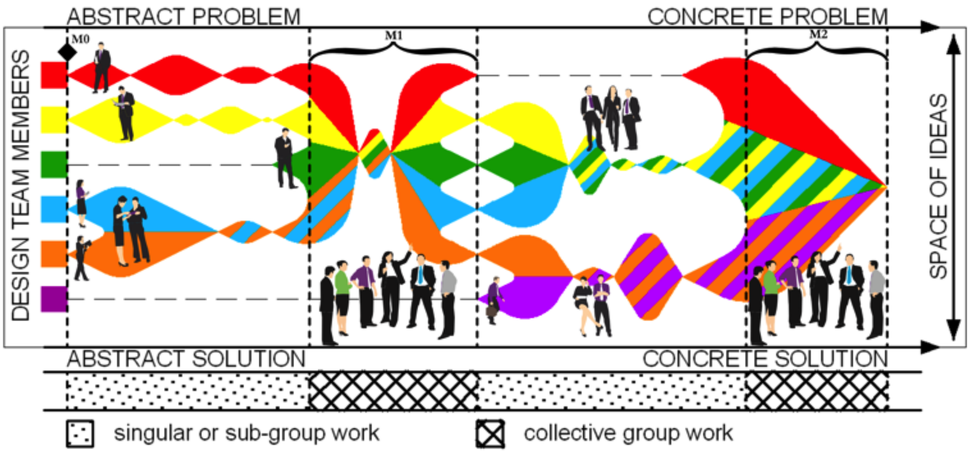

Figure 1. Dynamics of the preliminary design process according to Methodological Circulation

In Figure 1, we propose a visual schema for the dynamics of a design activity. Each colour represents a person (the team has six members, as we selected to consider design teams between four and eight people). There is a swing between singular and collective activities (i.e. meetings), whose dynamic will be described in subsection 2.4. Design team members can work singularly or in groups and subgroups (mix between colours). The composition of the team evolves according to the particular phase of the PDP, e.g. external company management can intervene only in meetings where strategic decisions are taken. This dynamic is meant to be recursive throughout each design activity.
Design teams achieve not only concrete solutions, but also a better understanding of the problem. Problem and solutions co-evolve during the design process (Maher et al., 1996) (Dorst et al., 2001) from an abstract to a concrete level (left to right) through a heuristic divergent-convergent process (creation and synthesis) that ends in a common deliverable (convergence of colours). The CSCWD system should support this dynamic, especially the shift between individual and collective work and the alternation of convergent and divergent thinking.

2.3 Collaborative problem-solving in collocated design activities

Meetings are collocated sessions of collaborative work. To simplify, we call them milestones. In MC, collocated collaboration (Olson et al., 2002) is defined as a mix between Maher's et al. (1998) three forms of collaboration: Exclusive (each designer performs a different activity during a collective meeting), Dictator (the project manager lead the collective meeting) and Mutual (every designer performs the same activity during collective meeting).

During design meetings, the designers share their conceptual ideas through the use of intermediary objects (Vinck and Jeantet, 1995) and verbal communication. Intermediary objects have different roles and three main features: mediation, transformation (or translation), and representation (Boujout and Blanco, 2003). They represent the common objectification of a conceptual idea, and serve as a mediator. These intermediary objects can be product representations (sketches, mock-ups, virtual or physical prototypes, etc.) (Darses, 1997) or project representations (scenarios, tasks, planning, risks, organization charts, etc.) (Shen et al., 2002).
The supportive device and tools should support the shift from closed to open objects (Vinck and Jeantet, 1995) to foster cooperation between designers. Additionally, an affording interaction with these tools can facilitate their use by all design team members. Those intermediary objects are constructed by the design team during the meetings, thus the CSCWD system should support this construction.

2.4 Group composition and the role of the project manager

MC relies three categories of actors: experts, users and management (at an internal lower level with the project manager and an external higher level with company management).
Experts are all the people that are solicited for a particular knowledge or know-how; they can be user experts, domain experts, design experts, communications experts, or feasibility specialists (Keinonen and Takala, 2010). Users are involved in order to contribute their feedback. The project manager, who represents the first level of management, is charged with facilitating the previously described *echo feedback-based exploration* of the paths within the problem/solution space. He or she interacts with the project ecosystem dealing with the constraints and the opportunities. The project manager must also decide upon the planning of the design activities and facilitate the work of the designer by promoting the right design tactic. Design strategy depends upon the proper use of creativity methods (e.g. brainstorming) and synthesis methods (e.g. value/risk analysis). We introduce the notion of *design toolbox*. Ideally, a *design toolbox* contains all relevant design methods.
The role of a supportive device is to guarantee the support and the availability for the largest possible number of design tools. It should support the possibility of easily shifting from one tool to another while permitting the reuse of data produced by the previous tool.

2.5 Research questions and hypotheses

Our general research question is: How can we improve the performance of the preliminary design process? We hypothesize that:
1) A design tactic such as Methodological Circulation may improve the preliminary design process.
2) CSCWD systems are a better supportive technology for such a design tactic than traditional paper based ones. Specifically, their use can:

1. Enhance the cognitive problem solving abilities of the design teams.
2. Foster cooperation through “open” intermediary objects.
3. Offer a more efficient knowledge capitalization and management.

We chose a co-evolutionary approach to conceive the TATIN-PIC platform and the associated *design toolbox* (Guerra et al., 2012), following the above-mentioned hypotheses.

3 INTEGRATION OF THE MC DESIGN TACTIC ON A DESIGN SUPPORT TOOL: TATIN-PIC PLATFORM

Effective preliminary design teams require alternating stages of discussion, exploration and diverging activities, coupled with stages of focus, decision-making and convergence. Providing a design team with an interactive tabletop can fulfil the diverging activities and an interactive board can satisfy the converging activities. Rogers and Lindley (2004) explain the differences between such horizontal displays and vertical displays for groupware: the tabletop surface ushers face-to-face collaboration, prompting opportunities for the sharing and discussing new ideas, while the interactive board promotes shoulder-to-shoulder collaboration, where participants focus and reflect upon the content.
Coupling the devices with a data connection allows designers to build a multi-surface work environment. This allows the team to be able to switch seamlessly between the horizontal and vertical surface, shifting content from one to the other whenever the activity could benefit from a different style of collaboration (Jones et al., 2011). The project manager has access to the *design toolbox* through a menu, available on every device of the TATIN-PIC platform.

In search of an affording interaction paradigm, we designed the principal means of interaction with the TATIN-PIC system to be based on tactile multitouch interaction. The tactile interaction has shown its potential as an easily understandable interaction modality. For example, because the gestures are a much more visible method of interaction, new users can easily copy and understand interaction techniques performed by expert users. TATIN-PIC should supports exclusive, mutual and dictator collaboration. We believe that digitalized intermediary objects shared on the system are more "open" than the traditional counterpart on traditional supportive technologies. Intermediary objects are more accessible (easier to manipulate, to retrieve, more visible) and design team members can interact together using these objects during collaborative meetings. The digital nature of data allows a better knowledge management, especially concerning the capitalization of the work and the automatic publishing of the minutes. The TATIN-PIC platform is a co-evolution of technical capabilities offered by the advancement of the technologies and of the design strategies.
Figure 2 shows both the concept and the real use of the TATIN-PIC platform (Jones et. al., 2012). An interactive tabletop and an interactive board display are the two primary components of the system, and it is also possible to connect secondary personal devices (personal PCS, tablets, smartphone, board and table). The TATIN tabletop has a screen size of 1.6m by 1.4m (5 feet 3 inches by 4 feet 8 inches), the screen resolution is 1920 pixels by 2160 pixels and the multi-touch input technology is based on a laser light plane. The TATIN board display has a screen size of 2.5m by 1.15m (8 feet 2 inches by 3 feet 9 inches), the screen resolution is in Ultra HD, with 2730 pixels by 1536 pixels and the multi-touch input technology comes from an infrared overlay frame.

Figure 2. TATIN-PIC platform: concept and real use during for PDP activities

4 PRELIMINARY RESULTS FROM ETHNOGRAPHIC DESIGN OBSERVATIONS

4.1 Experimental protocol

Our validation protocol is based on an empirical study using ethnographic observation methods. We observed design teams performing task identification and project planning activities over the course of two 3-hours long work sessions. In the first session, groups were given a design brief concerning an all-terrain vehicle (ATV) project and asked to generate and categorize all the tasks that must be completed before the industrialisation of the product. Hence, the participants constructed a planning of the project and performed a PERT analysis to identify the critical path. The second session involved the optimization of the planning and the production of a written report with a Gantt chart. We choose to study a planning activity, because it is generally a preliminary design activity. Additionally, it is a problem-solving task, well suited for our purposes. Finally, we wanted to test an activity other than brainstorming, which has already been observed (Gidel et al., 2011).
A total of 20 female and male engineering practitioners, aged from 22 to 39 years old, were observed. Four groups were formed; two groups performed the task in a traditional design environment using paper, pen, brown paper, mono-user PCs and Post-it notes® (control condition) and two other groups performed the same activity using the TATIN-PIC environment (TATIN-PIC condition).
Thus, each group consisted of five engineering practitioners: a project manager and 4 members. An external male senior level person represented the management for both conditions.

To have a homogeneous level of skills, we chose people with no practical experience concerning the supportive technologies and the above-mentioned planning activity.

Table 1. Schedule of the design observations

SESSION	CONTROL	TATIN-PIC	ACTIVITIES	DATE
1	Group A	Group B	Task identification, PERT analysis	D+0
1	Group C	Group D	Task identification, PERT analysis	D+7
2	Group A	Group B	Planning optimization	D+14
2	Group C	Group D	Planning optimization	D+21

There is no general consensus around the possibility of comparing environments such as interactive tabletops and their traditional counterparts (Nunamaker, 1991) (Huber, 1990). We believe that this comparison is possible in terms of performances evaluation and in ethnographic observations on how the system influences the work of the design teams.
Full-HD camcorders (4 for the TATIN-PIC condition and 3 for the control condition) are positioned to cover as many angles as possible. High quality audio is captured through directional microphones. The independent camera streams and audio tracks are later synchronised and brought together in a four-screen view. Figure 3 provides an example frame from the four-camera view to illustrate the two different design environment used during our observations.

Figure 3. A preliminary design activity: control condition (left) and on TATIN-PIC (right)

At the end of each session a feedback questionnaire is given to each participant. In each of the questionnaires, participants are asked to evaluate certain subjective criteria of their experience on a 7-point Likert scale. They also were invited to add written comments on each of the criteria evaluated. All experiments were conducted in French and therefore the results were translated to English by the authors. Finally, design teams are interviewed during a 20-minute semi-structured focus group about their opinions on the design observations.

4.2 Analysis methods and preliminary qualitative results

We present the preliminary results obtained during the design observations through field analysis, video recordings, written and oral comments. The quantitative data concerning time are inferred from the video recordings. Considering our experimental setup, we expect the performances to be impacted by the *Hawthorne effect*[2] (Mayo, 1949) to a certain degree that we are not able to measure.
From the video recordings we retrieved and merged the average temporal value (of session 1 and session 2) for the principal actions performed. We identified 7 categories: the training time, the time to read the design brief (fixed at 15 minutes by the management), the time spent on the horizontal surface, the time used for the shift from the horizontal surface to vertical one and vice versa, the time spent on the vertical surface, the time used to realize the minute of the work and the time saved before the end of 180 minutes. Figure 4 (accuracy 2,8% or ± 5 minutes) shows the time repartition for each condition.

[2] A term referring to the tendency of some people to work harder and perform better when they are participants in an experiment.

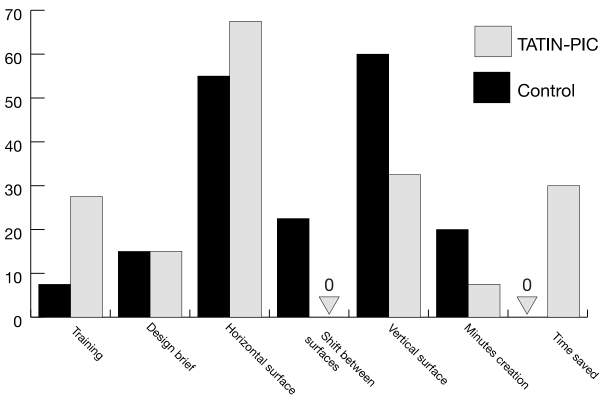

Figure 4. Time (in minutes) for each condition

Enhancement of design teams' cognitive problem solving abilities: Field notes and preliminary video analysis show a problem-solving dynamic that respects the alternation between divergent and convergent thinking. This process has been facilitated in both conditions (control and TATIN-PIC) by the orientation of the supportive surfaces. Horizontal surfaces have been used mainly for creating and sharing ideas, while vertical surfaces to reflect upon the generated contents. *"The horizontal table is more friendly and restful, it allows a better simultaneous work of the different actors"*, said subject T5 in the group D1*; "The vertical surface is a very good synthesis tool, to have an overview of the work done*", said subject T3 in the group B1.

The TATIN-PIC system supports this dynamic with a faster and more natural circulation of data between the different surfaces (no need to rewrite, move, and reposition the post-its). As shown Figure 4, the circulation between horizontal and vertical devices (passage between supports) and the alternation between divergent and convergent cognitive posture (that are related according to Rogers and Lindley's hypothesis), takes more or less 25 minutes in control condition but is done instantly with TATIN-PIC system.

The overall performances are better on TATIN-PIC (cf. Figure 4). Even if we suspect an influence of the Hawthorne effect, we notice a temporal gain. The only activity that has not proved any advantage in the use of the TATIN-PIC system is the work on the horizontal surfaces. This is mainly due to some interaction problems that virtual tactile keyboards still present: *"It's a little difficult to write on virtual tactile keyboard, if we could have a real keyboard it would be more effective"*, said subject T2 in group B2.

Impact on the dynamics of the collocated design meeting: In the control condition, we notice more exclusive collaboration (work on separate parts of the problem, negotiating occasionally by asking advice from the other). In TATIN-PIC, we experience major implication through mutual collaboration. The newness and agreeableness of the device and the open nature of the objects on the table could explain those results: *"the fact of seeing and interacting with each other jobs is good for collective work"*, said subject T4 in the group B1. This leads to a better construction of a shared vision of the task and augmented group awareness, fostering cooperation. Subject T4 in the group B1 said that the system *"allows each project actor to be involved in a fun and dynamic way"; "The contemporary interaction of the design teams with the system creates a group dynamic and a corporal involvement, and so all the collaborators are involved."* said subject T1 in the group B1.

The "dictator" role fits better in TATIN-PIC system than in control condition (we noticed that sub-groups formed around the most charismatic person, sometimes conflicting each other, lowering the performances (Cf. Figure 4) and the engagement: *"...sometimes people are not very involved."* said subject T2 in group C2. This suggests that, during collocated collaborative design sessions, the exclusive collaboration model is more preferable for traditional supportive technology (Maher et al. 1998), while a *dictator-guided mutual* collaboration may be better suited for the new CSCWD supportive technology.

Knowledge capitalization and management: The TATIN-PIC platform leads to a better capitalization and storage of the documents produced. The TATIN-PIC platform proves to be particular effective when it comes to session minute redaction. The groups working on TATIN-PIC experienced (and positively appreciated) all the advantages of a digital document (portability, storage, research, etc.). Apart our field notes and video recording we have precise feedback directly from the participants such as: *"Excellent. All is automatically generated, PERT and Gantt."* said subject T3 in the group D1.

Despite having a personal PC, control group members are obliged to re-copy contents from paper model (Post-it notes representing the PERT analysis) to a Microsoft Project document on their PCs. This compels one team member to concentrate only on the role of the "scribe", lowering group awareness and performances. We have specific negative comments confirming this point, such as: *"A member of the group is obliged to do the reporting and in this case his participation to the project is limited",* said subject T1 in the group A1. Moreover, the use of the *design toolbox* has been judged easier and more powerful (in term of accessibility) on TATIN-PIC. For example, to shift from a categorization of tasks to a PERT analysis, the control group has to move, reshape and sometimes rewrite, all the Post-its. On TATIN-PIC, one hand gesture allows transferring the contents of the "virtual post-it" to a different format, adapting them for a PERT analysis while preserving their same semantic value.

Co-evolution of solutions and the problem: During the final focus group, particularly the groups of the TATIN-PIC condition, talked about a growing awareness and comprehension of the problem and the solutions, while progressing with the activity. It is particular interesting to note that this evolution seems to be promoted by the open role of the intermediary objects: *"Being able to interact together with the objects on the platform, let us easily create a common vision of the problem and thus to share better our personal concepts",* said subject T4 in the group B2. Reymen et al. in their study on the co-evolution (2009) proposed the idea of a bridging concept between problem and solution, the "boundary objects"; this experiment seems to confirm this idea. We did not find, instead, any traces of the "concept of use" (behaviours) that was proposed in their article as the boundary object. We suppose that this is due to the fact that their research on the topic are only based on architectural design sessions where behaviours play an important role. Moreover, the division of the problem as the domain of the client, and of the solution as the domain of the architect is too simplistic. We suggest considering the intermediary objects as the bridge that joins problem and solutions in collective design activities. However, the ontological role of the intermediary objects in this context is still worth investigating.

5 CONCLUSION AND FUTURE PERSPECTIVES

CSCWD systems can provide a suitable support for the preliminary design process (PDP). However, for PDP to be efficient, design strategies and methods should be adapted for this kind of system. This is why we chose a co-evolutionary design approach, based on four key factors, which resulted in the co-construction of the TATIN-PIC platform adapted for the Methodological Circulation design strategy. To validate this co-evolutionary approach, we conducted experiments to compare traditional (pen, paper and personal computer) and CSCWD environments during a preliminary design planning activity. The first results suggest that the TATIN-PIC platform supports better the activities of the design teams. TATIN-PIC seems to support the Methodological Circulation principles, for what concern a fluid circulation between devices. The circulation among design tools is yet to be completely studied. The use of vertical and horizontal surfaces follows the hypothesis of Roger and Lindley (2004); the designers' problem-solving approach has enlightened a succession of divergent and convergent moments.

We have positive qualitative feedback related to group awareness and the predominance of dictator and mutual collaboration in collaborative design meetings on TATIN-PIC, in contrast with the proposition of Maher et al. (1998). We also have direct feedback from the user interviews that confirm our conjecture of a co-evolution of design solutions and problems. Interactive tabletops show a better predisposition to promote the shift from closed intermediary objects to "open objects", improving the accessibility to the various participants and therefore fostering cooperation. The group awareness and engagement is higher in the TATIN-PIC condition. Overall the design activities done on the TATIN-PIC platform requires less time. The capitalization of the knowledge created during the PDP activity is easier and more accessible on TATIN-PIC. Finally, the role of the project manager has been identified as crucial and worth of further investigations.

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